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(54) Title: WELDING HEAD

(57) Abstract

A welding head (50) including upper and lower probe members (60, 62) and probe pin (64). The upper and lower probe members (60, 62) are independently actuatable and biased to follow the profile of a workpiece and supply a balance load to opposed surfaces of a workpiece during welding operation.

WELDING HEAD

BACKGROUND OF THE INVENTION

The present invention relates to a welding head. In particular, the present invention relates to a welding head for friction stir welding applications.

Friction stir welding is a process of welding component parts together using friction heat generated at a welding joint to form a plasticized region which solidifies joining workpiece sections. A welding head is used to generate friction heat along a welding joint. The welding head includes a welding probe which is inserted into a joint between workpiece sections. The probe includes a pin that is inserted into the joint and a shoulder which is urged against an upper surface of the workpiece. The pin and shoulder spin to generate friction heat to form a plasticize region along the joint for welding operation.

For welding operation, a workpiece is supported by a rigid table or backplate typically formed of a steel plate. Rigid backplate stabilizes the actuation force of the upper shoulder to maintain the integrity of the workpiece so that the workpiece does not bend or deform under the load. To maximize strength of the joint between workpiece sections, the welded portion should extend the entire thickness of the workpiece. To assure that the weld extends the entire thickness, sufficient friction heat must be generated between upper and lower surfaces of the workpiece so that the plasticized region extends between upper and lower surfaces of the workpiece .

Typically, the thickness of a workpiece can vary along the joint. Variations in the workpiece thickness can vary pin depth or extension into the

workpiece joint. If pin depth does not extend sufficient thickness, the plasticized region does not extend the entire thickness of the workpiece causing stress notches in the joint. For a smaller thickness, pin can extend too close to the backplate so that workpiece becomes joined to the backplate as a result of the welding operation. These and other problems are addressed by the present invention.

SUMMARY OF THE INVENTION

The present invention relates to a welding head with adjustable probe or pin depth to compensate for variations in workpiece thickness. The welding probe includes an upper probe member and a lower member and a pin movably supported relative to the upper probe member. Upper and lower probe members are coupled to separate forge actuators and are urged against upper and lower surfaces of the workpiece. The pin and upper and lower probe members rotate to generate friction heat at the weld joint. The forging force of the upper and lower probe members generates friction heat at the upper and lower surfaces of the workpiece to provide sufficient friction heat through the thickness of the workpiece. The forging force on the upper and lower actuators is balanced to maintain the integrity of the workpiece and limit bending and distortion. The biased upper and lower probe members follow workpiece profile so that pin depth is adjusted based upon thickness of the workpiece at the joint.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of an embodiment of a welding head of the present invention.

FIG. 2A is an illustration of a plasticized region for a prior art probe including an upper shoulder and fixed pin.

FIG. 2B is an illustration of a plasticized region for a probe including upper and lower probe members.

FIG. 3 is a schematic control feedback for forging force Fg_1 on upper probe member and forging force Fg_2 on lower probe member.

FIG. 4 is a cross sectional illustration of a welding head of the present invention.

FIG. 5 is a perspective illustration of a fixture supporting a welding head of the present invention.

FIG. 6 is a schematic illustration for force feedback Fg_1 and Fg_2 of upper and lower probe members.

FIG. 7 is a schematic illustration of force and position control feedback for upper and lower probe members.

FIG. 8 is a detailed illustration of an operation control embodiment for upper and lower probe members.

FIG. 9 is a schematic illustration of a flexible mounting assembly for a welding head to follow the contour of shaped forms or components.

FIG. 10 is a perspective illustration of a flexible mounting fixture supporting a welding head.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

FIG. 1 schematically illustrates an embodiment of a welding probe 50 for friction welding application. Welding probe 50 welds workpiece sections 52, 54 at joint 56. Welding probe 50 is connected to a spindle drive 58 to rotate probe 50 for welding operation. As shown welding probe 50 includes an upper probe member 60, a lower probe member 62 and a probe pin 64. As shown, lower probe member 62 is rigidly connected to probe pin 64 and is movable therewith. Lower probe

member 62 and probe pin 64 are slideably supported as illustrated by arrow 66 relative to upper probe member 60 for adjusting pin 64 extension relative to upper probe member 60 for use for workpieces of various thickness and for compensating for thickness variations in a workpiece as will be explained.

As shown, upper probe member 60 includes an upper shoulder 72 and lower probe member 62 includes a lower shoulder 74. For operation, upper probe member 60 is supported so that shoulder 72 abuts an upper surface 76 of workpiece sections 52, 54. Pin 64 extends through joint 56 and shoulder 74 of lower probe member 62 abuts a lower surface 78 of the workpiece sections 52, 54.

An upper forge actuator 80 is coupled to the upper probe member 60 and a lower forge actuator 82 is coupled to the lower probe member 62 and pin 64. For welding operation probe 50 rotates and upper and lower forge actuators 80, 82 supply forging forces Fg_1, Fg_2 to upper and lower probe members 60, 62 as illustrated by arrows Fg_1, Fg_2 respectively.

Rotation of pin 64 and upper and lower probe members 60, 62 generates friction heat to create a plasticize region for welding workpiece sections. To assure that the weld extends the thickness of the workpiece, probe should form a plasticize region that extends between upper and lower surfaces 76, 78 of the workpiece. In FIG. 2A, a profile of plasticize region 92 formed by a prior art probe tapers from a thicker region 94 at an upper surface 76 of the workpiece to a thin region 96 proximate to a lower surface 78 of the workpiece. Stress notches or root openings form if the weld does not extend the entire thickness of the workpiece.

In contrast, as illustrated in FIG. 2B, upper and lower probe members 60, 60 form a plasticized region 98 that includes thicker regions 100, 102 at the upper and lower surfaces 76, 78 and a taper center region 104. The friction heat generated on the workpiece to form the plasticized region 98 is a function of the total forging force of the upper and lower probe members or $Fg_T = |Fg_1| + |Fg_2|$. Thus friction heat generated by the probe is increased by the lower probe member 62 operating in cooperation with the upper probe member 60.

Upper and lower forge actuators 80, 82 and spindle drive 58 are coupled to controller 106 as schematically illustrated in FIG. 1 for operation. Controller operates upper and lower forge actuators 80, 82 to maintain upper and lower probe members 60, 62 or shoulders 72, 74 in abutment with upper and lower surfaces of the workpiece to compensate for variations in workpiece thickness and profile and to provide a balanced load on opposed surfaces of the workpiece. Controller 106 can be a digital controller or an analog controller set to supply a balanced forging force for upper and lower actuators. A digital controller 106 includes a processor and memory for storing programmed instructions.

In particular, controller operates lower forge actuator 82 to maintain appropriate spacing between upper and lower probe members 60, 62 to adjust pin 64 depth relative to workpiece thickness and variations in workpiece thickness. Controller is programmed or set to supply balanced forging force $Fg_1 = Fg_2$ to the upper and lower probe members 60, 62 to rigidly support the workpiece to reduce off axis loads to the workpiece and limit bending or distortion of the workpiece during welding operation. FIG. 3 illustrates a simplified

embodiment for controlling operation of upper and lower forge actuators 80, 82. As shown in FIG. 3, controller 106 uses an input or command forging force 108, which is used to control upper and lower actuators 80, 82. In FIG.3, input forging force 108 = Fg_1 and Fg_2 is the inverse as illustrated by block 109. In an alternative embodiment, input force 108 = Fg_t and $Fg_1 = Fg_t/2$ and $Fg_2 = - Fg_t/2$. Controller 106 includes upper and lower process control 110, 112 which provides operating control to upper and lower forge actuators 80, 82 as illustrated by lines 114, 116 based upon input parameters 108, 109 and control feedback 118, 120. During welding operation, feedback 118, 120 includes force feedback as will be explained to maintain a balanced load to the workpiece to limit deformation or bending of the workpiece. Control of the upper and lower probe members 60, 62 biases members 60, 62 against the workpiece to maintain proper pin 64 depth based upon workpiece thickness and variations in workpiece thickness. Thus, as described, welding probe provides a plasticized profile having thicker regions relative to upper and lower surfaces 76, 78 of the workpiece to provide a relatively rigid weld joint across the thickness of the workpiece joint, while rigidly supporting the workpiece to limit bending and distortion.

FIG. 4 is a detailed cross-sectional view of an embodiment of a welding probe 50 including actuatable upper and lower probe members 60, 62. In the embodiment shown, probe 50 includes an outer housing 122 and an inner housing 124 rotationally connected to outer housing by bearings 125. Upper probe member 60 is formed by inner housing 124. Pin 64 is slidably supported in housing 124 via rod 126. Probe member 62

is connected to pin 64 to slidably support lower shoulder 74 relative to upper shoulder 72 formed by housing 124. Spindle shaft 128 is coupled to housing 124 to rotate housing 124 (upper probe member 60, lower probe member 62 and pin 64) by operation of spindle drive 58 for welding operation. In one embodiment, spindle drive 58 includes an inline torque transducer for spindle control. Spindle control includes simultaneous torque and RPM (revolutions per minute) control.

As shown schematically, upper forge actuator 80 is connected to outer housing 122 to position and actuator upper probe member 60 as will be explained. In the embodiment shown, lower forge actuator 82 is a fluid actuator supported in inner housing 124 and coupled to rod 126 connected to lower probe member 62 and pin 64. Fluid actuator includes an actuation chamber 130 and piston 132. Rod 126 is connected to piston 132 operable in chamber 130. Actuator fluid is delivered to chamber 130 from fluid source 134 for bi-directional movement as illustrated by arrow 136. Fluid is delivered from fluid source 134 to rotating housing 124 by fluid commutator or slip rings 138. Fluid is delivered through channels 140, 142 for bi-directional actuation as illustrated by arrow 136. Preferably, fluid source 134 is a hydraulic fluid although other fluids can be used.

Although a fluid actuator is shown, application is not limited to a fluid actuator, and alternate actuators can be used, such as an electrical or mechanical actuator, with a fluid or electrical actuator interface, for communication between the rotating probe and stationary housing for actuation. In the embodiment shown, cooling fluid is supplied from a

cooling fluid source 144 to channels 146 in the probe through fluid commutator 138 for temperature control during welding operation. Housing 122 includes upper and lower portions separated by a sealing ring 148 for operating fluid containment.

As previously described force feedback 118, 120 is used for actuating control of upper and lower probe members 60, 62 and pin 64 to maintain a balance Fg_1 and Fg_2 on the workpiece as illustrated schematically in FIG. 1. Additionally, in the embodiment illustrated in FIG. 4, a displacement sensor 150 (for example, a linear voltage displacement transducer "LVDT") is coupled to rod 126 for position feedback control for pin 64 extension and separation distance between upper and lower probe members 60, 62 as will be explained.

As shown in FIG. 5, for welding operation, probe housing 122 is supported for movement along a probe track 152 supported by a welding fixture 154. Fixture includes a base 156, and posts 160, 162 which extend from base 156 to support probe track 150 above a workpiece table or backplate 164. Probe track 152 is movably coupled to tracks 166, 168 along posts 160, 162 to raise and lower probe 50 as illustrated by arrow 170 for welding operation. Table 164 includes a groove 172 or alternately two separately spaced table sections can be used to support the workpiece. Workpiece joint is aligned with groove 172 or separation for placement of the lower probe member 62 underneath the workpiece supported by table 164. As described, probe track 152 supports probe 50 for movement along a welding joint of a workpiece supported by table 164 as illustrated by arrow 174.

Fluid actuators 176, 178 are coupled to probe track 152 to raise and lower track 152 and probe 50 as illustrated by arrow 170. Actuators 176, 178 position probe 50 relative to workpiece and supply forging force to upper probe member 60 through housing 122. Although a particular fixture is shown, application is not limited to the particular fixture. For example, table 164 can be movably supported relative to base 180 as illustrated by arrows 180 for probe placement along a welding joint. Bi-directional placement of the probe as illustrated by arrows 180 facilitates complex welding operation along a curved joint in addition to straight line welding along a straight joint. Operation of the actuators 176, 178 can be independently controlled to vary rake angle 184 of the probe for contour welding operations, as will be explained.

As shown schematically in FIG. 6, force feedback 118 for upper probe member 60 is measured by force transducer 188 connected in series with force actuator 80 (fluid actuators 176, 178) and upper probe member 60. Force feedback 120 for lower probe member 62 is measured by a pressure sensor assembly for measuring pressure differential between chamber portions 190, 192 of fluid actuator 82. Although particular force feedbacks 118, 120 are described, force feedback 118, 120 is not limited to the particular embodiment described.

As previously explained, in one embodiment, position feedback from, for example, displacement sensor 150, can be used for probe control. FIG. 7 illustrates a control schematic for force and position control. As shown schematically, upper and lower process control 110, 112 receive and process force 108, 109 and position 194, 196 input or command and force 118, 120 and

position feedback 198, 200. Upper and lower process control 110, 112 includes mode switching for switching between force and position control. Mode switching includes a mode controller 202 or operating actuator 80, 82 between force and position control to maintain force and position parameter within command parameters or limits.

Mode controller 202 switches mode control between force and position control based upon the force and position error between the program commands 108, 109, 194, 196 and feedback 118, 120, 198, 200. For example in FIG. 7, mode controller 202 provides force control to maintain force feedback relative to command parameters and switches to position if force feedback 118, 120 is within command parameters 108, 109 and provides position control to maintain position feedback within command parameter and switches to force control when position feedback 198, 200 is within command parameters. A proportional integrated controller (DID) provides force and position control and bumpless mode switching between force and position control.

As illustrated in FIG. 8, position feedback 198 can be used to maintain minimum separation Δz between upper and lower probe members 60, 62 based upon workpiece thickness Δt. For example, Δz can be controlled based upon preprogrammed command parameters based upon the profile of the workpiece. In one embodiment, upper and lower process control 110, 112 adjust the position of upper and lower probe members 60, 62 to adjust Δz (separation between upper and lower probe members 60, 62) to correspond to workpiece thickness or minimum separation command parameter. In particular, the position of lower probe is fixed relative to a workpiece supported by table 164. For

separation control, actuator 82 adjusts the position of upper probe member 62 for Δz, and the position of the probe member 60 is also adjusted the same increment as lower probe member 62 by actuator 80 to compensate for the adjustment of lower probe member 62 to maintain the elevation of lower probe member 62 aligned with table 164.

Position feedback can be used to compensate for profile or dimension changes in the workpiece based upon position commands. As shown in FIG. 8, upper and lower probe members 60, 62 can be adjusted relative to workpiece profile data 204. Workpiece profile data Δz 204 can be measured or downloaded off-line or during the welding process by various sensors such as optical sensors to provide position commands 194 for operation. For example, the thickness of the workpiece may fluctuate or the thickness may increase Δt. To compensate for profile variations, lower process control 112 operates forge actuator 82 based upon position commands for the workpiece profile so that the separation distance of upper and lower probe members 60, 62 is $\Delta z = t + \Delta t$ where:

Δz -is the separation distance between upper and lower probe members 60, 62

t - is the original workpiece thickness; and

Δt - is the thickness change in the workpiece.

For a fixed support, upper process control 110 operates actuator 80 to adjust the position of upper probe member 60 relative to lower probe member 62 to maintain the elevation of lower probe 62 aligned with table 164 as follows $zu_2 = zu_1 + \Delta t$ where:

zu_2 -is the adjusted position of the upper probe;

zu_1 -is the original position of upper probe; and

Δt -is the workpiece thickness change.

For operation outside a fixed reference frame (relative to table 164), position feedback 198, 200 from upper and lower probe members 60, 62, as illustrated in FIG. 7, and position commands can be used by controllers for placement of upper and lower probe members in abutment with upper and lower workpiece surfaces 76, 78. For example, z_u, z_1 and Δz can be used for placement of upper and lower probe members 60, 62 based upon position feedback z_u, Δz and position commands for z_u, Δz where:

Δz -is the displacement measurement of sensor 150 corresponding to separation of upper and lower probe members 60, 62;

z_u -is the position of upper probe member measured relative to elevation of housing 122 based upon measurement by position sensor 206 shown in FIG. 6; and

z_1 -is the position of the lower probe member calculated based upon $z_u + \Delta z$.

Position commands for z_u, z_1, and Δz can be derived from workpiece image or profile data which is uploaded to controller memory for execution or can be derived during the welding process via various sensors such as laser or optical sensors. As shown in FIGS. 9-10, in one embodiment, head is flexibly supported to flexibly couple the head (upper and lower probe members) to follow the contour of the workpiece for adapting head 50 for welding complex shapes and forms. In FIG. 9, head 50 is flexibly supported to pitch and roll relative to an x axis by first and second frame members 210, 212

for sloped or contour welding of surface 208. Head 50 is pivotally connected first frame member at trunions 214 to roll relative to the x-axis as illustrated by arrow 216. Frame member 210 is pivotally connected to frame member 212 to support the head 50 to pitch as illustrated by arrow 218. As shown in FIG. 10, pitch and roll actuators 220, 222 adjust the position of the head 50 so that the surface of the head 50 (for example, upper and lower shoulders 72, 74) are normal to the surface of the workpiece for contour welding via operation by controller 106 based upon programmed data or profile measurements received during the welding operation via optical or laser sensors.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. Although probe members have been described relative to an upper and lower orientation, it should be understood, that probe members are not restricted to an upper and lower orientation and the upper and lower probe members can be oriented in any opposed relation.

WHAT IS CLAIMED IS:

1. A welding probe comprising:

a first probe member having a first shoulder;

a second probe member having a second shoulder;

a probe pin movably coupled to the first probe member and the second probe member being rigidly connected to the probe pin to support the second probe member in opposed spaced relation relative to the first probe member;

a first actuator operably coupled to the first probe member to provide an operating force to the first probe member;

a second actuator operably coupled to the probe pin and second probe member to provide an operating force to the second probe member; and

a controller operably coupled to the first and second actuators and set to provide balanced operating forces to the first and second actuators.

2. The welding probe of claim 1 including

a first force feedback coupled to the controller and first actuator; and

a second force feedback coupled to the controller and second actuator, the controller operating the first and second actuators based upon first and second force feedback.

3. The welding probe of claim 2 wherein load feedback controls separation between first and second probe members based upon workpiece thickness.

4. The welding probe of claim 2 wherein at least one of the first or second force feedback is measured by a force transducer.

5. The welding probe of claim 2 wherein at least one of the first or second force feedback is measured by actuating pressure of the actuator.

6. The welding probe of claim 1 including position feedback coupled to the controller.

7. The welding probe of claim 1 including force and position feedback coupled to the controller wherein force feedback and position feedback control separation between first and second probe members based upon workpiece thickness.

8. The welding probe of claim 4 including force and position feedback coupled to the controller and the controller is set to mode switch between force and position control.

9. The welding probe of claim 1 including force and position feedback coupled to the controller wherein position feedback controls separation between first and second probe members based upon workpiece thickness.

10. The welding probe of claim 6 wherein position feedback controls at least Δz, z_u or z_l of upper and lower probe members wherein Δz is the separation distance between the upper and lower probe members; z_u is the position of the upper probe member and z_l is the position of the lower probe member.

11. The welding probe of claim 1 wherein controller receives position commands for at least one of Δz, z_u or z_l.

12. The welding probe of claim 1 wherein the controller includes position data for contour welding complex shapes.

13. The welding probe of claim 12 wherein position data includes a memory stored image of the profile of the workpiece.

14. A welding head comprising:

a housing;

a probe rotationally coupled to the housing including:

a first probe member;

a probe pin slidably supported relative to the first probe member, and a second probe member rigidly connected to the probe pin;

an actuator coupled to the probe pin and second probe member for slidably moving the probe pin and second probe member relative to the first probe member and supplying a forging force to the second probe member; and

an actuator interface member between the housing and rotating probe to operationally connect the actuator in the rotating probe.

15. The welding head of claim 14 wherein the actuator is a fluid actuator and the actuator interface is a fluid commutator for fluid interface between a fluid source and the fluid actuator.

16. The welding head of claim 14 including a displacement sensor coupled to the probe pin for measuring probe pin extension.

17. The welding head of claim 14 including a pressure sensor assembly coupled to a fluid actuator chamber for measuring actuation pressure for determining actuating force of the second probe member.

18. The welding head of claim 14 including cooling channels in the probe and a fluid interface from a fluid source to the cooling channels in the rotating probe for delivery of cooling fluid to the rotating probe for welding operation.

19. A method for welding a joint between first and second workpiece sections comprising steps of:

locating a rotating probe in the joint between workpiece sections;

supplying a balanced force against first and second opposed surfaces of the workpiece sections; and

rotating the probe while supplying the balanced force on opposed surfaces of the workpiece sections for welding operation.

20. The method of claim 19 further comprising the steps of:

providing force feedback against the first and second surfaces of the workpiece; and

adjusting the force on the first and second surfaces of the workpiece based upon the force feedback.

21. The method of claim 9 further comprising the steps of:

providing first and second probe members; and

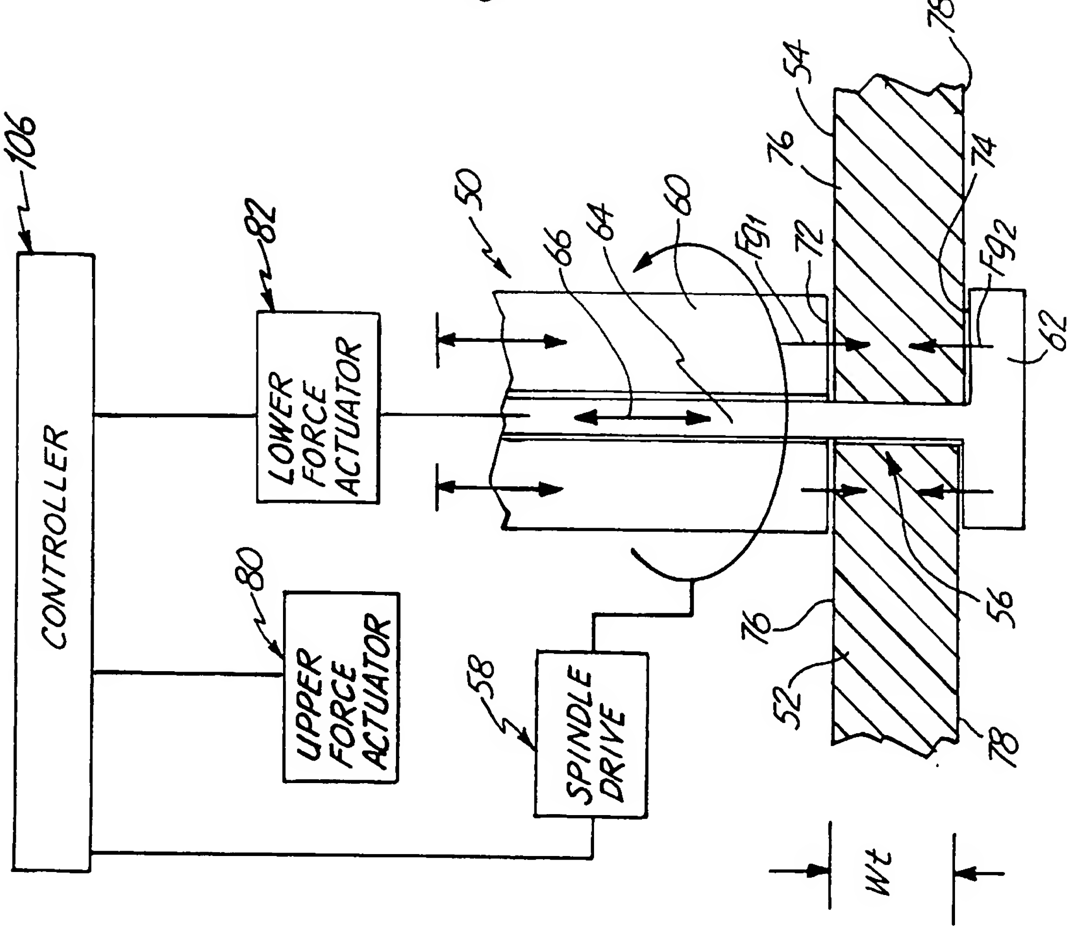
adjusting separation distance between the first and second probe members relative to thickness of the workpiece sections.

22. The method of claim 21 further comprising the steps of:

monitoring the position of the first and second probe members; and

adjusting the position of the first and second probe members relative to workpiece profile.

Fig. 1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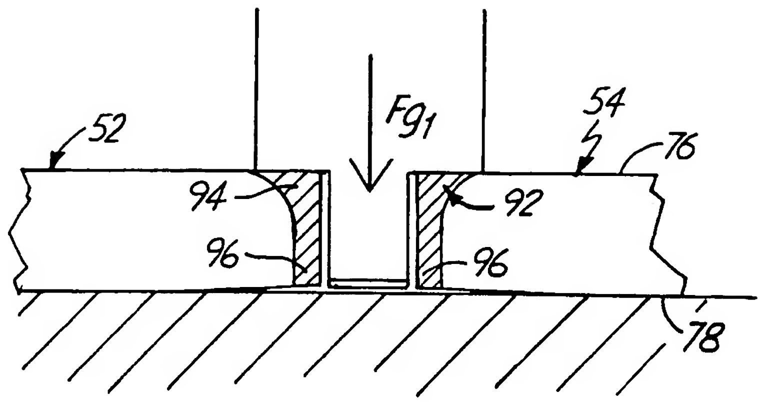

52
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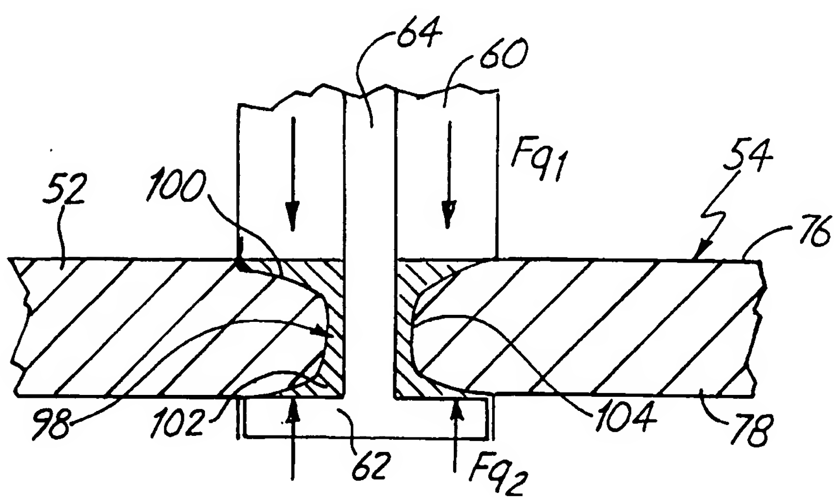
Fig. 2A



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Fq2

Fig. 2B

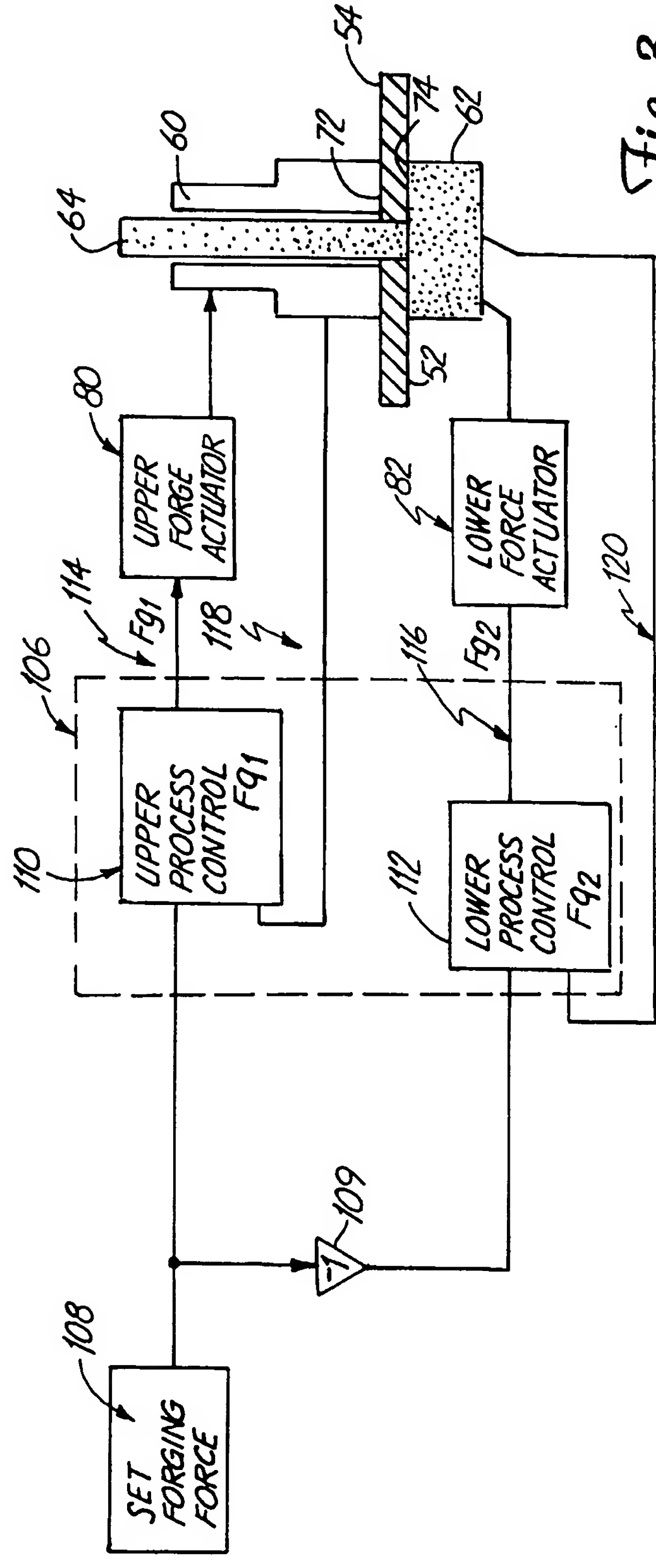
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Fig. 3

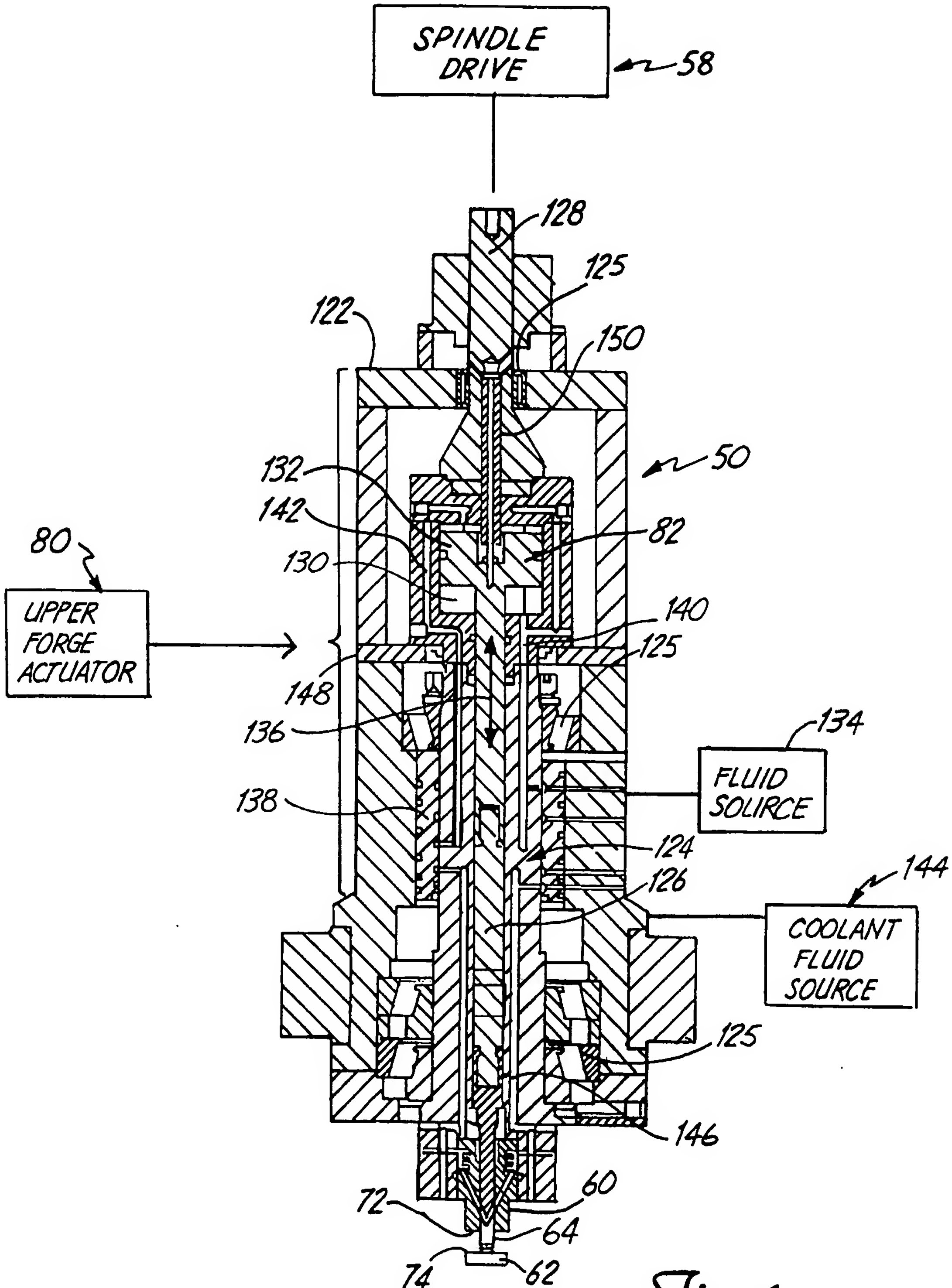
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Fig. 4

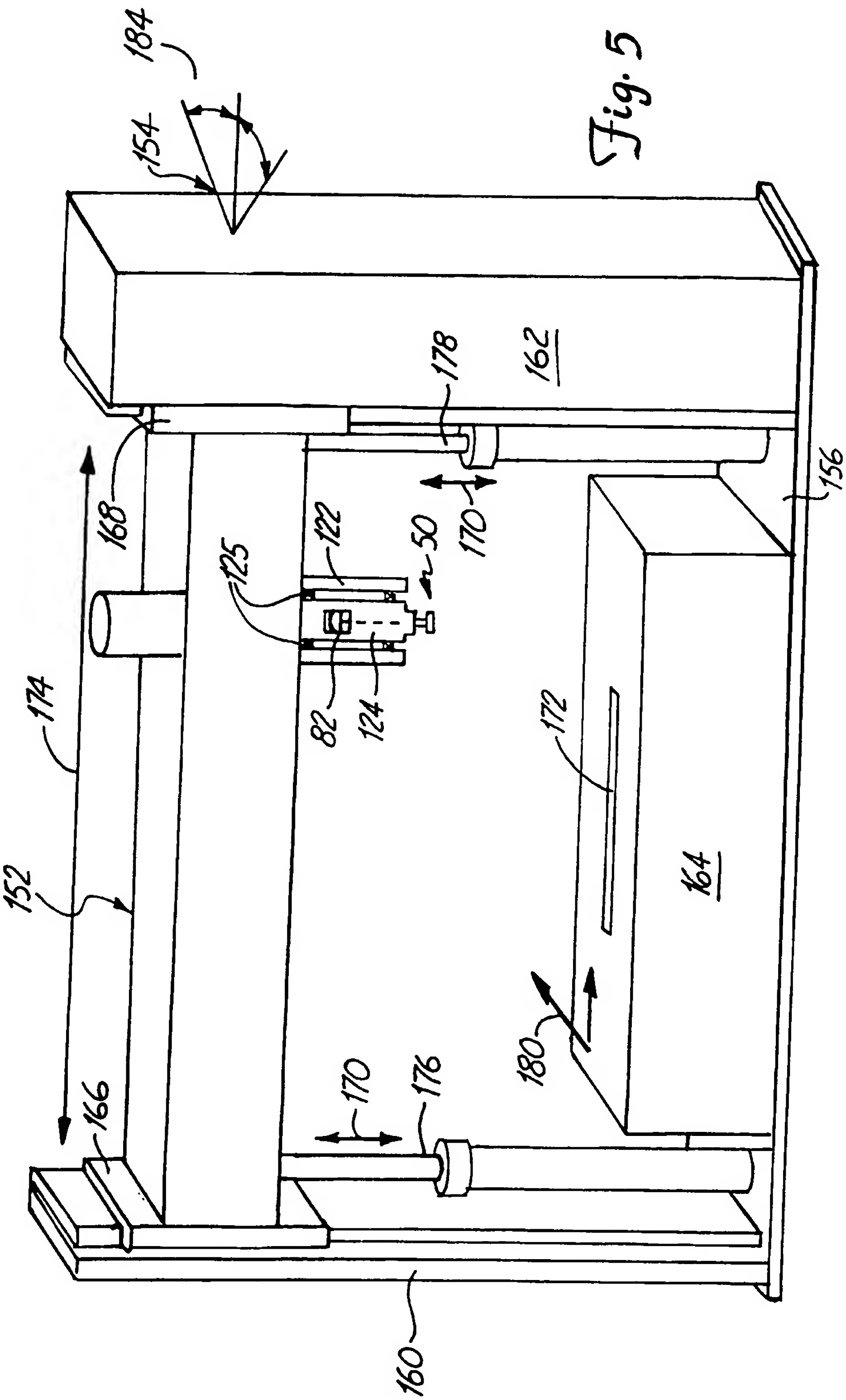
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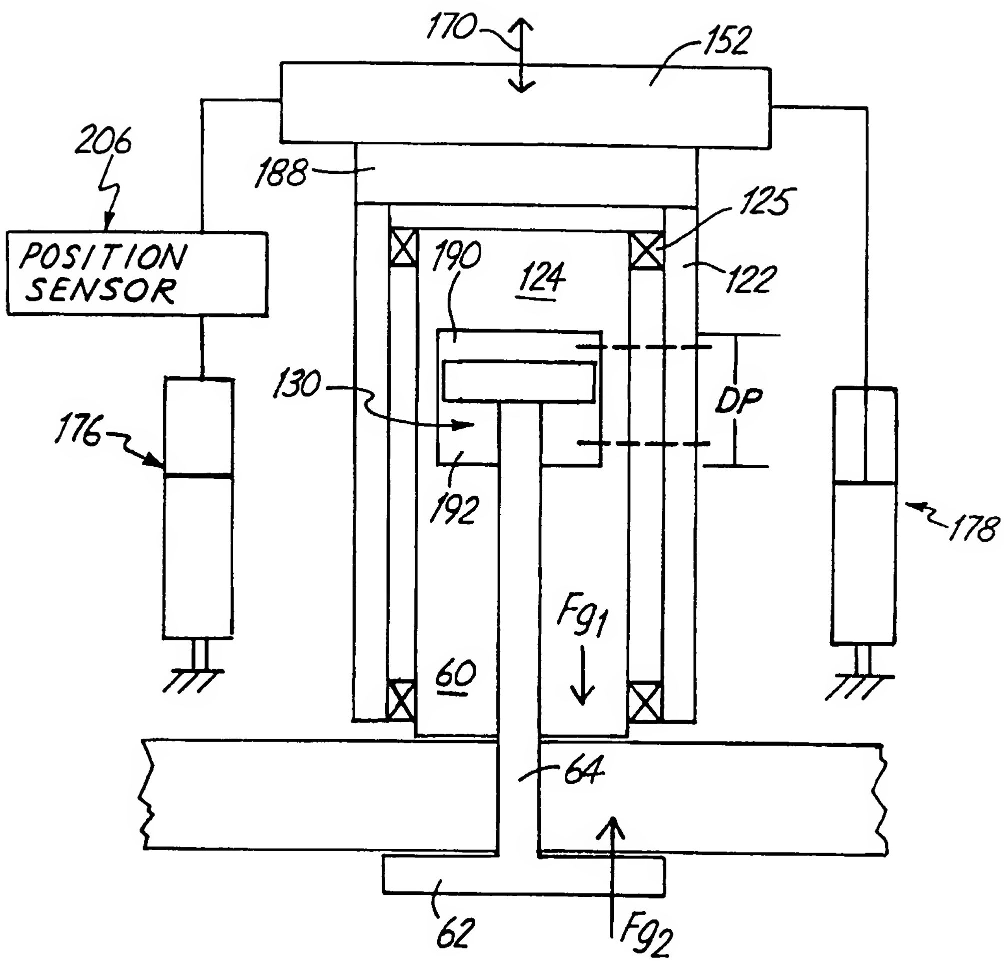
Fig. 5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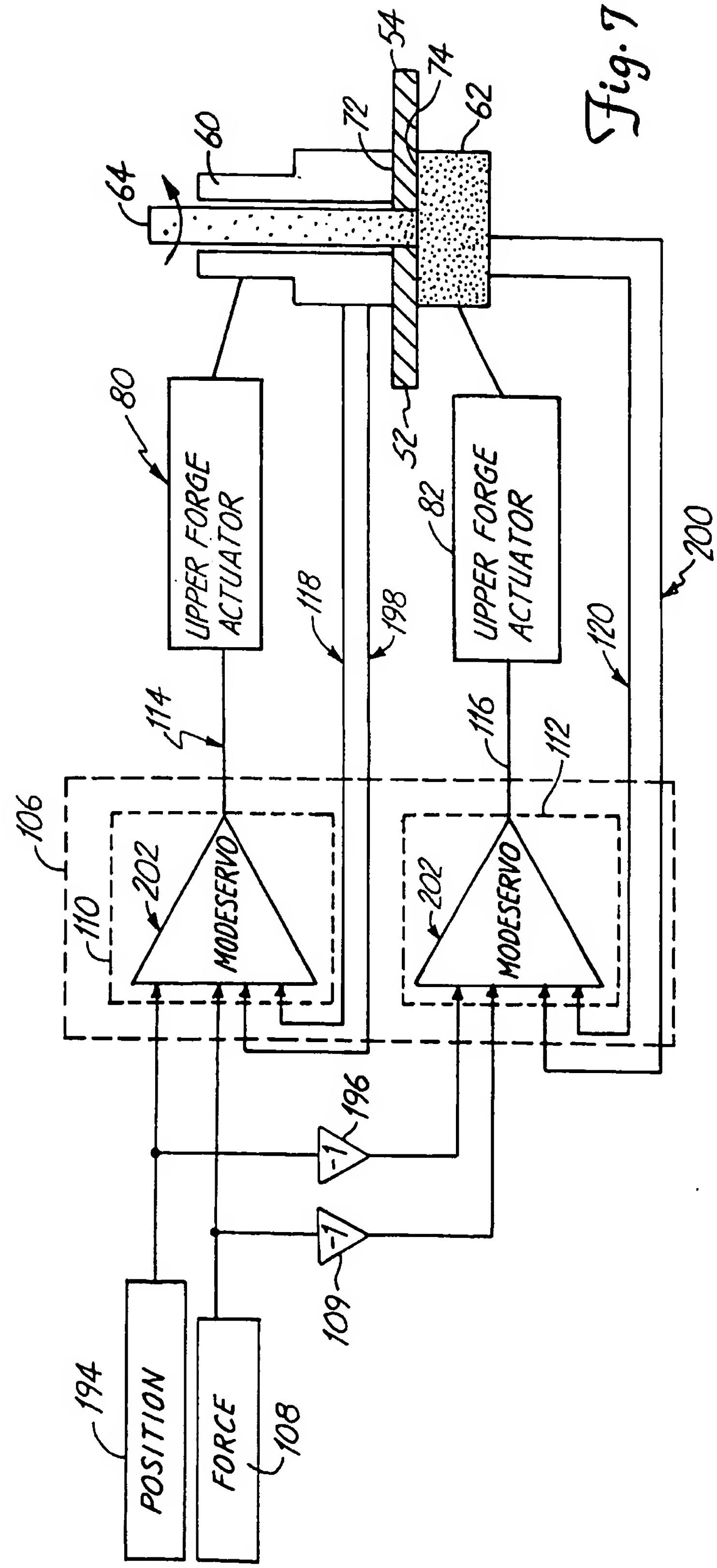
Fg2

Fig. 6



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UPPER FORGE ACTUATOR
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109
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POSITION
FORCE
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Fig. 7

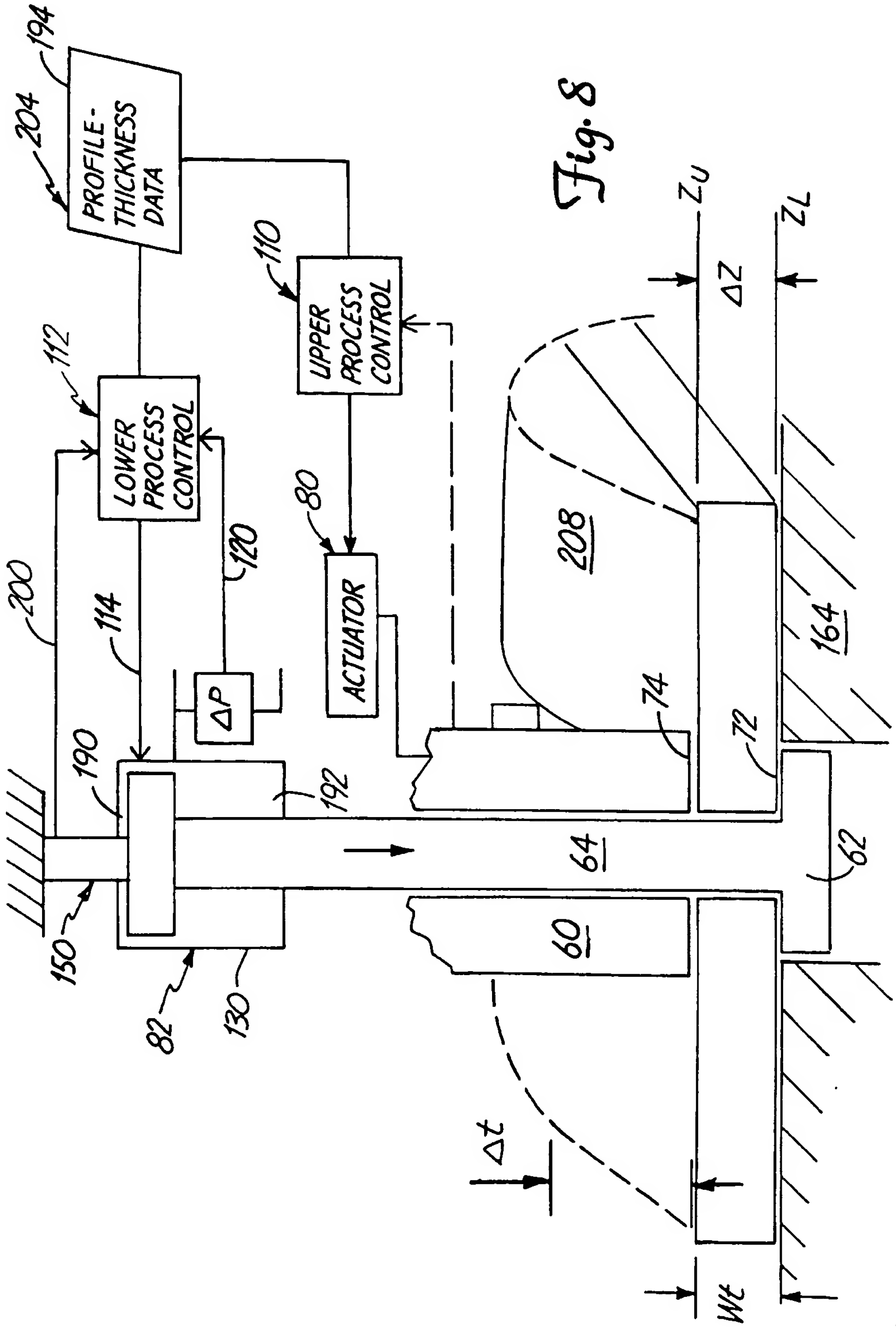
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Fig. 8

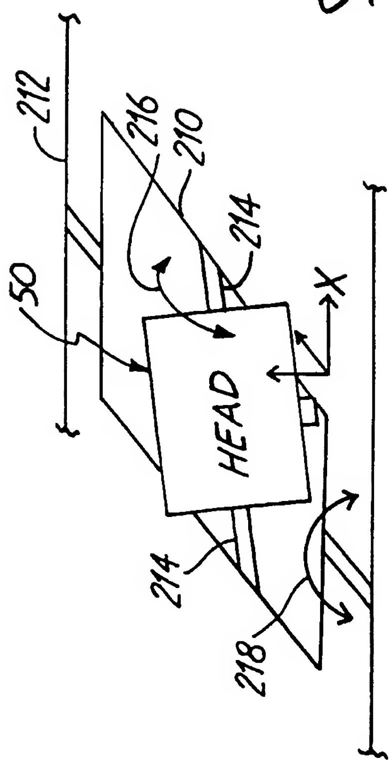
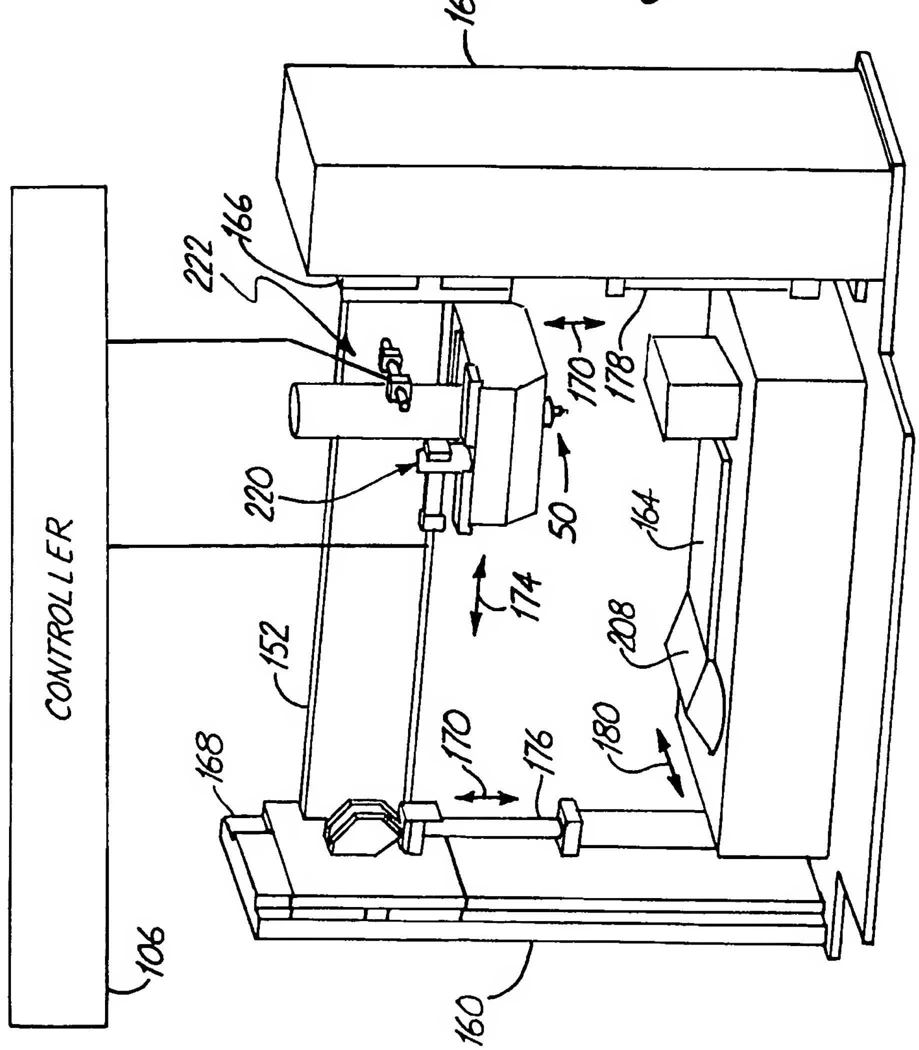


Fig. 9

Fig. 10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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/15148

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B23K 20/12; B27C 5/00; B23Q 15/00
US CL :228/2.1,112.1; 144/142, 356, 134.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 228/2.1,112.1; 144/142, 356, 134.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WEST
SEARCH TERMS: friction stir welding

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US 5,893,507 A (DING et al) 13 April 1999, col. 5, lines 5-43 and 50-64, col. 6, lines 1-56, and abstract.	2, 4, 6, 7, 8, 11, 12, 14
Y	US 5,486,262 A (SEARLE) 23 January 1996, col. 5, lines 12-67, col. 6, lines 1-27 and 39-48, and fig 3.	1, 3, 5
Y	US 3,817,439 A (KIWALLE et al) 18 June 1974, col. 4, lines 41-54, col. 8, lines 59-67, col. 9, lines 1-11.	15, 17, 18
Y	US 5,518,562 A (SEARLE et al) 21 May 1996, col. 2, lines 36-59, col. 9, lines 33-62.	19, 20, 21, 22
Y	US 5,697,544 A (WYKES) 16 December 1997, col. 3, lines 39-48	16

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
17 SEPTEMBER 1999	05 OCT 1999

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/15148

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,558,265 A (FIX, JR.) 24 SEPTEMBER 1996.	1